



PATENT SPECIFICATION

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(54) Title: Fast acting auxiliary electronic governor for active power control and ramp rate control of wind farms

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Fast Acting Auxiliary Electronic Governor for Active Power Control and Ramp Rate Control of Wind Farms

The present invention relates to the field of energy; in particular to wind farm power control and electrical grid systems stability.

This invention improves the method of control of wind farm power output and dispatchability of wind farm power systems to the electrical grid in line with transmission system operator (EirGrid) grid code requirements.

Context: EirGrid Grid Code Version 5 — Section: WFPS1.5.4: Ramp Rate

- Frequency Response Ramp Rate
- Active Power Control Set-Point Ramp Rate
- Wind Following Ramp Rate

Under European Union energy directive 2009/28/EC, Ireland is required to meet 2020 mandatory renewable targets including Ireland's (RES-E) target of renewables contribution to gross electricity consumption; 40% by 2020. In order to meet this target, Ireland must increase penetration of renewable generation on the electrical grid. This involves conventional synchronous generators being displaced by (non synchronous) generators such as wind farm power systems. However, grid stability must be maintained or the grid will collapse causing major blackouts.

The stable, reliable operation of electrical grid systems involves a continuous balance between energy supply (electrical generation) and demand (electrical load or consumption). The rate at which demand (load) varies with respect to supply (generation) affects the grid frequency. If energy demand is greater than energy supply, the alternating frequency decreases. Alternatively, if energy demand is less than energy supply, the frequency increases. The rate of change of frequency is known as ROCOF.

In Ireland, according to TSO EirGrid grid code version 5, the maximum permissible rate of change of frequency on the system for generation units to stay connected is 0.5Hz/s. If the ROCOF is greater than 0.5Hz/s, significant amounts of generation could be lost, leading to system collapse.

Traditional power system design and operation was based on conventional rotating synchronous generators, supplied with reliable, predictable, controllable energy such as fossil fuels. These generators provided services to the grid such as inertial response, high damping and voltage regulation.

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1. Provision of Inertia (rotating mass / stored kinetic energy).
2. High damping (rapid response time).
3. Voltage Regulation.

10 The Problem

Wind turbine generators are difficult to control to a high degree of accuracy for a number of reasons:

1. They are very large machines (with rotors up to 150m).
2. They depend on a highly variable energy input: wind.
- 15 3. They are slow to react / delayed response (control systems depend on information from an instrument measuring wind downstream from the rotor).
4. Doubly fed wind turbines have a speed control range of approximately +/-30% (i.e. sub or super synchronous) whereas full converter wind turbines have a wider speed control range. Doubly fed wind turbines cannot find the optimal speed matching points when controlling the power to levels below approximately 25% of their available active power (AAP), resulting in difficulty achieving controllable, stable (Designed Minimum Operating Levels) DMOL levels of 12%.
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Ireland is particularly vulnerable to this problem due to the highly complex terrain, high turbulence intensity and dramatic wind shear & wind veer profiles (variation of wind speed with height and wind direction with height, respectively).

Modern wind turbines are controlled with complex control systems that actively pitch (adjust the angle of) the blades to increase or reduce power output. In order to achieve this level of stability, grid code compliance standards for wind farm power stations have become extremely complex and onerous on the control of individual wind turbine generators. This has forced wind turbine manufacturers to comply with these standards by programming the control algorithms to operate outside the machines original design certification, with subsequent wear and tear.

In terms of the grid code requirements, control of generators refers not only to controlling the power output but also to ramp rate control (rate of increase or decrease of power output) and reducing overall power output to DMOL (designed minimum operating level) which must be no greater than 12% of the WFPS (wind farm power station) registered capacity.

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Statement of the Invention

Current state of the art in wind technology has dump and diversion loads in order to regulate power systems, including the provision of reserve power for under frequency control and also used for controlling the speed of small wind turbine systems. However, this invention improves on the state of the art featuring additional important grid compliance functionality for both active power control and ramp rate control.

This invention relates directly to

1. Achieving the ramp rate control specified by the grid code requirements.
2. Achieving DMOL (Design Minimum Operating Level); by reducing power output to no greater than 12% of registered capacity.
3. Enhancing wind farm active power and ramp rate control during normal operation and curtailment.

Brief Description of the Drawings

The device consists of:

- Variable braking loads with cooling system
 - These can be either multiple step or infinitely variable or a combination of both.
 - Cooling system can be air or water or other.
- Variable super capacitor banks (connected in series or parallel)
 - These can be either multiple step or infinitely variable or a combination of both.
- Electronic controller (capable of receiving external signals and set-points and based on control algorithms; dispatches the required active and reactive load)
 1. Auxiliary Electronic Governor Active Power Controller
 2. Auxiliary Electronic Governor Ramp Rate Controller
 3. Variable Braking Loads
 4. Switching Power Electronics (For example: [SCR] Silicon-controlled rectifiers, [IGBT] Insulated Gate Bipolar Transistors, [TRIAC] Triodes for Alternating Current etc.)
 5. Super Capacitors
 6. Auxiliary Electronic Governor – active power control
 7. WFPS (Wind Farm Power Station)

- 8. WFPS Ramp Rate Control System
- 9. WFPS Active Power Control System 25
- 10. Main Contactor
- 11. Bypass Contactor

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Power Control Signals:

MV_A = Measured Value at Grid (Point of Connection)

MV_B = Measured Value at Auxiliary Electronic Governor

SP_A = Active Power Set-point (TSO Grid Code Defined)

10 SP_B = Ramp Rate Set-point (TSO Grid Code Defined)

Variable Braking Loads:

R_v = Variable Resistive Load

R_1 = Resistive Load 1

15 R_2 = Resistive Load 2

R_3 = Resistive Load 3

R_N = Resistive Load N

IAP_{SP} = Instantaneous Active Power Set-point as calculated by WFPS Controller.

20 AP_{MV} = Active Power Output at WFPS Connection Point

AP_{SP} = Active Power Set-point (Dispatch signal from TSO).

K Threshold = AEG set-point Threshold, consisting of cut in (upper) / cut out (lower) set-points.

25 DMOL = The minimum Active Power output of Controllable WFPS where all WTGs are generating electricity and capable of ramping upwards at any of the specified ramp rates (given available wind), and shall not be greater than 12%. (Ref: EirGrid Grid Code v5, October 2013)

TMOL = Wind Turbine Technology Minimum Operating Level; as defined by manufacturer.

30 (For example; see curves TMOL1 and TMOL2, Fig 6.0)

Available Active Power = The amount of active power that the Controllable WFPS could produce based on current wind conditions. (Ref: EirGrid Grid Code v5, October 2013). (For example; see curve AAP, Fig 2.0)

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Wind Speed Frequency Distribution = Average Wind Speed Frequency Distribution curve based on 10 year, hourly average wind speed data from nine different Met Eireann synoptic stations. See Wind Speed Frequency Distribution curve Fig 6.0.

5 Detailed Description:

This invention relates directly to the grid code non-compliance element and also to improved wind farm active power control.

10 This device functions as a diversion load governor to control DMOL once the wind farm active power control system reaches its "limitation" as defined by the wind turbine manufacturer and technology which for DFIG technology may be greater than current grid code requirement of 12% of registered capacity, for example 25% of registered capacity or 25% of AAP (Available active power). The diversion set point becomes positive only when active power (megawatt) set point is less than (Technology limit set point in Megawatts, i.e. 15 TMOL).

This invention can function, not just at the lower range of wind farm active power control (i.e. DMOL) but also, during normal operation at a higher range of active power control serving as the priority active power controller over the wind farm.

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Advantages:

- Increases stability
- Increases reliability
- Takes stress from wind turbines (reduces operating costs)
- 25 • Reduces risk of non compliance (manufacturers being over conservative)
- Avoids wind farm going below DMOL and switching out individual turbines by dumping energy and maintain operation - this also extra benefit of avoiding delay due to start up sequences.

30 Drawing Detail Figure 3.0

The auxiliary electronic governor ramp rate controller operates in parallel with the WFPS ramp rate controller. It becomes active only when the active power 1 minute ramp rate or 10 minute ramp rates are in "alarm or impending alarm" status). The measured value in the ramp rate control mode is AP-Diversion load MV such that the wind farm main controller 35 does not see or react to the diversion load. The main wind farm control loop will eventually go from alarm to "normal" which will cause the diversion load control to reduce and stop.

Drawing Detail Figure 4.0

- Depending on the configuration; the auxiliary electronic governor can be designed to switch in discrete steps or provide soft starting functionality.
- The switching power electronics will vary depending on the functional requirement.
- $R_{\text{SETPOINT}} = \text{steps } (R_{1+N}) + \text{variable } (R_V)$

Drawing Detail Figure 5.0

- Discrete switching of loads is also possible using one fully variable power controller, and individual main contactors (10) and bypass contactors (11) for each load.
- For example: assume initially K1, K2, K3, K4, K5, K6, K7, K8 are open. Power set-point is set to 250kW. K2 closes, power controller increases from 0 - 250kW at specified ramp rate. When power controller reaches 250kW, K1 Closes & K2 Opens instantaneously. This process repeats for K3 and K4, K5 and K6, K7 and K8 etc. for fully variable power output.

Drawing Detail Figure 6.0

This drawing details the following example; low range active power and ramp rate control for auxiliary electronic governor.

- Typical 'Available Active Power' curve for wind farm power station.
- Typical 'Wind Speed Frequency Distribution' curve for a wind farm in Ireland.
- Achievable DMOL curve using the Auxiliary Electronic Governor at lower active power range control.
- TMOL 1 (25 - 40%) and TMOL 2 (25% DMOL) curves, indicating typical "turbine minimum operating level" curves depending on individual technology limitations of wind turbines generators.
- K Threshold = AEG set-point Threshold, consisting of cut in (upper) / cut out (lower) set-points.
- IAP_{SP} = Instantaneous Active Power Set-point as calculated by WFPS Controller.
- AP_{MV} = Active Power Output at WFPS Connection Point.
- AP_{SP} = Active Power Set-point (Dispatch signal from TSO).
- DMOL (designed minimum operating level) as defined in "EirGrid Grid Code Version 5, 07 October 2013" as the minimum Active Power output of Controllable WFPS

where all WTGs are generating electricity and capable of ramping upwards at any of the specified ramp rates (given available wind), and shall not be greater than 12% of Registered Capacity..

5 Drawing Detail Figure 7.0

This drawing details the higher range control band capability of the auxiliary electronic governor, whereby the device functions as lead active power and ramp rate controller for the WFPS.

- Typical 'Available Active Power' curve for wind farm power station.
- 10 • AEG Active Power Control, High Range Control Band

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Claims:

1. An active power control device which can be used to achieve DMOL (Designed Minimum Operating Level), consisting of an active power controller (1), with a set-point PID tunable closed control loop, controlling variable braking loads (3) through switched contactors and or infinitely variable switching power electronics (4) which may be used to achieve soft starting or perform discrete switching which operates in parallel with the WFPS active power control system (9) and can be and activated by the DMOL limitation set-point of the specific WFPS (7).
2. An active power control device as claimed in claim 1 with an additional ramp rate controller (2), which operates in parallel with the WFPS ramp rate control system (8).
3. An active power control device as claimed in Claim 1 or 2 with additional super capacitors (5) that enable both positive and negative active power control.
4. An active power control device as claimed in Claim 1 or 2 with two programmable modes of operation, high range active power control and low range active power control.
5. An active power control device which can be used to achieve DMOL (Designed Minimum Operating Level) as herein described with reference to the accompanying drawings.

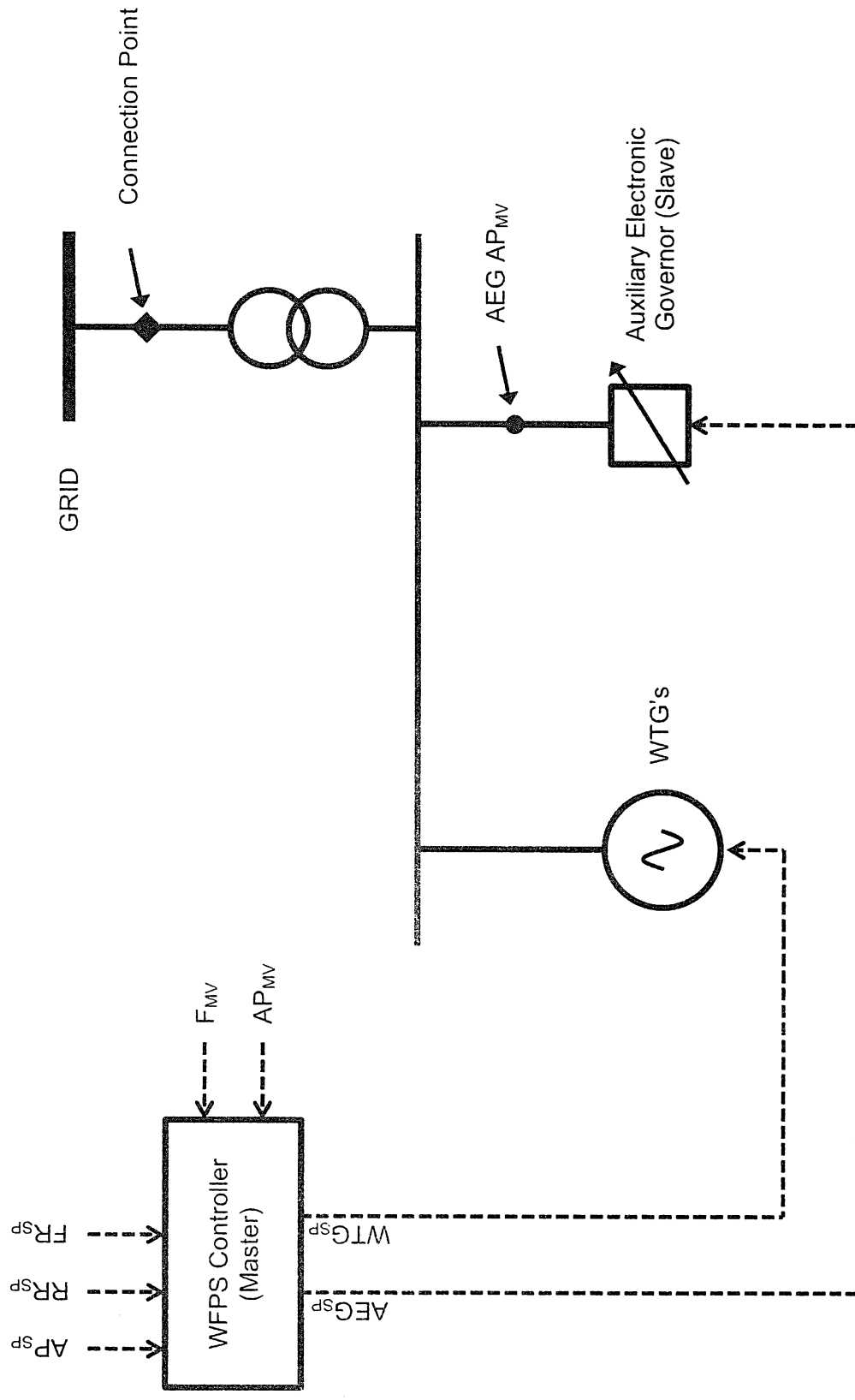


Fig. 1.0

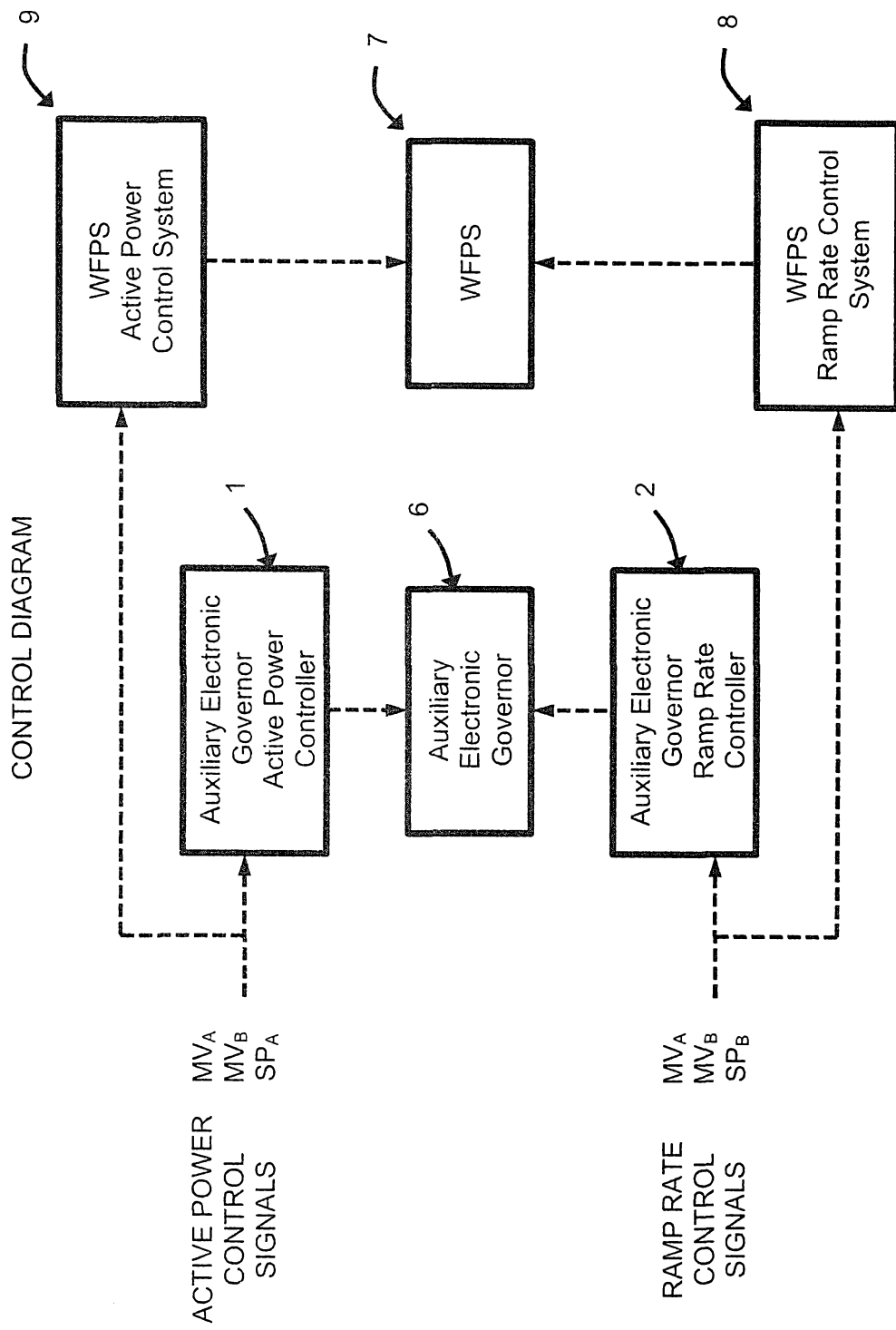
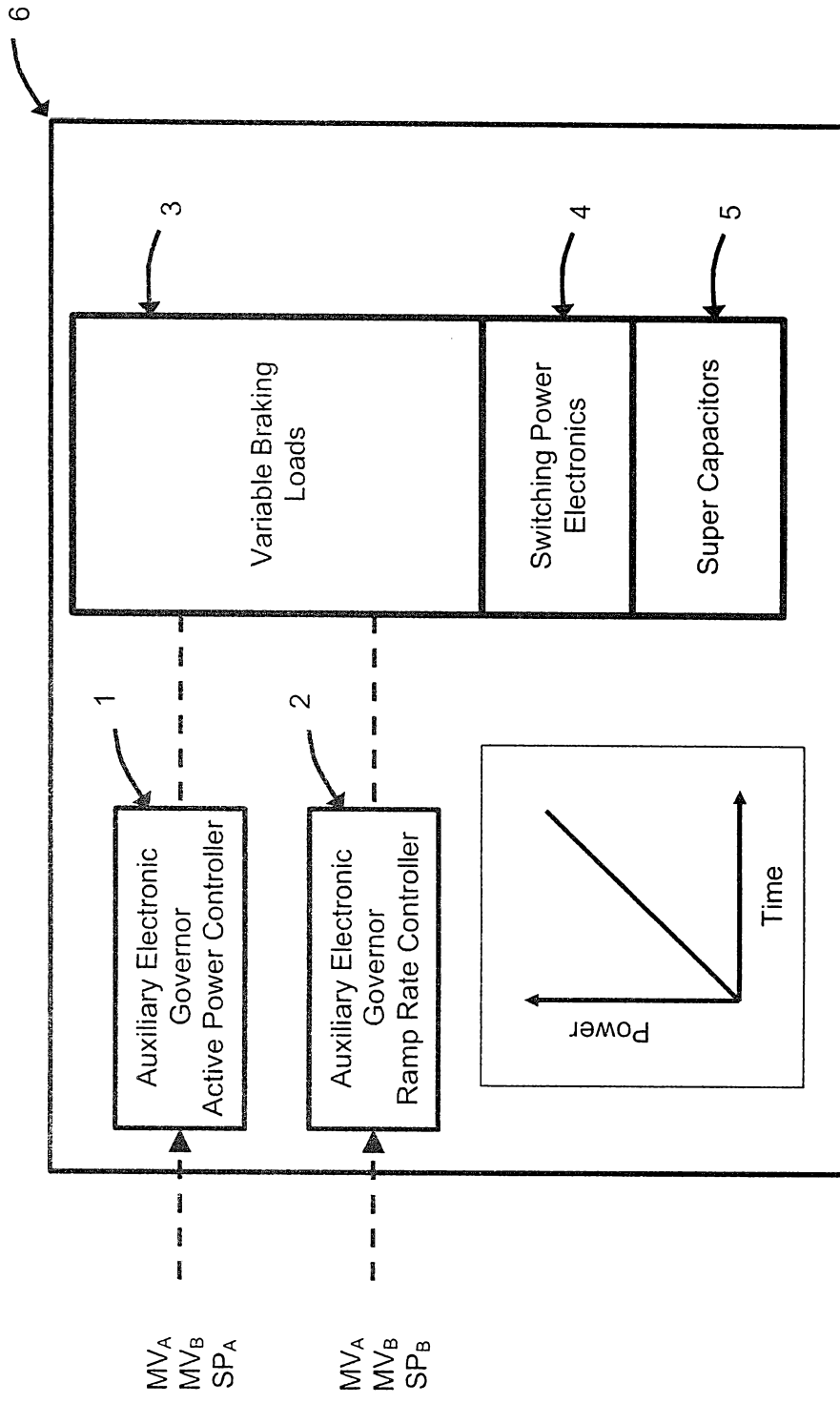


Fig. 2.0

AUXILIARY ELECTRONIC GOVERNOR (CONTROL DETAIL)



Signals &
Set-points

Fig. 3.0

AUXILIARY ELECTRONIC GOVERNOR & VARIABLE BRAKING LOADS (DETAIL)

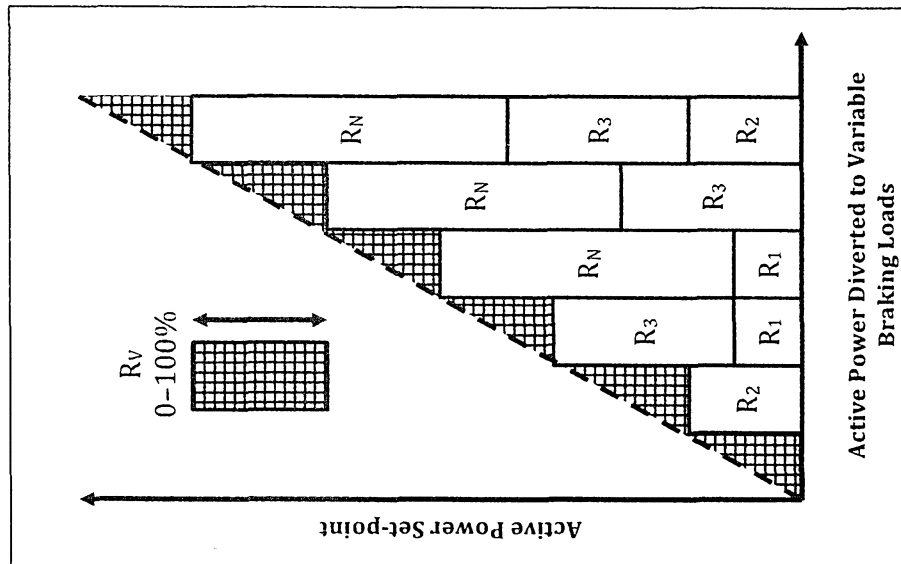
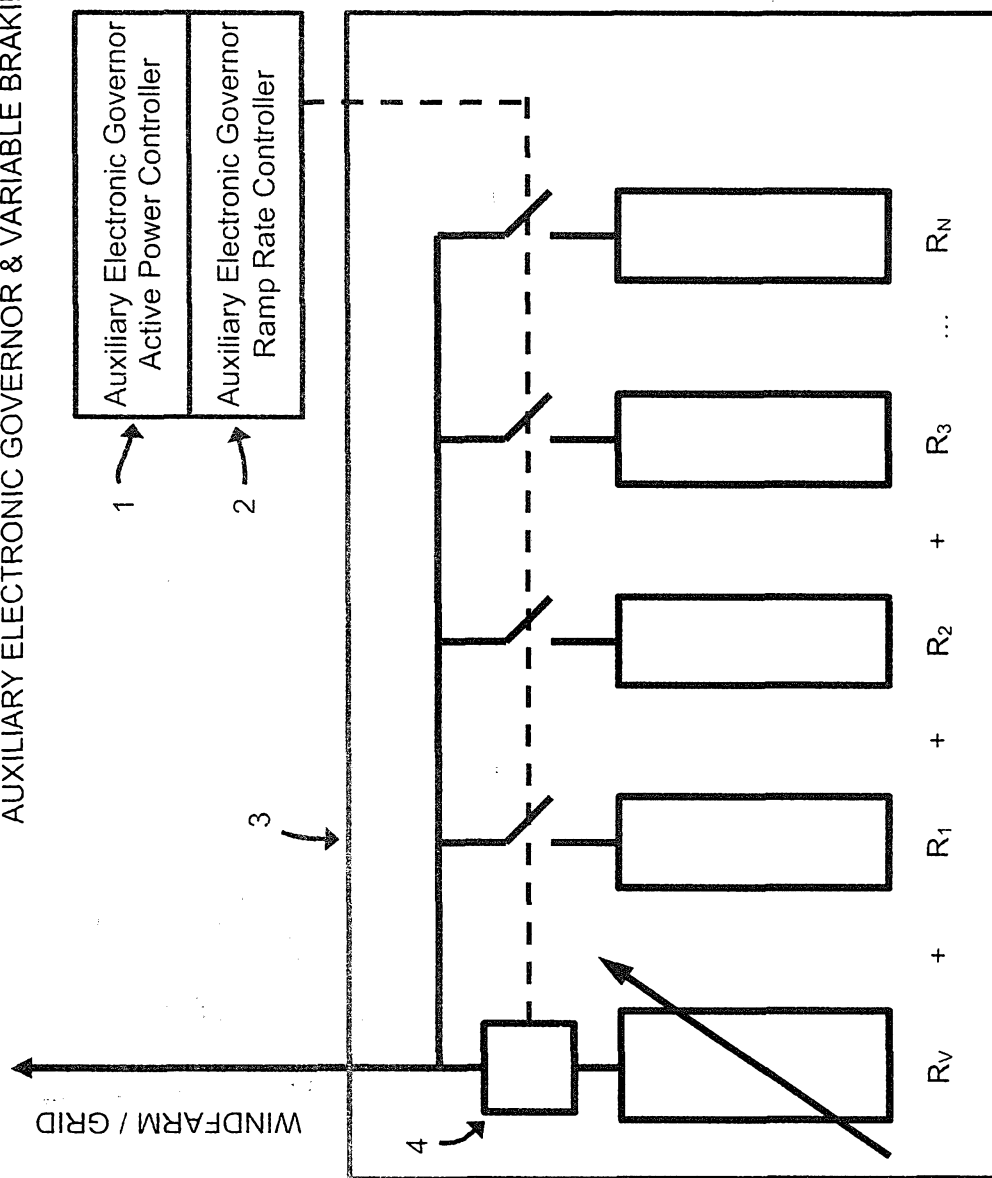


Fig. 4.0

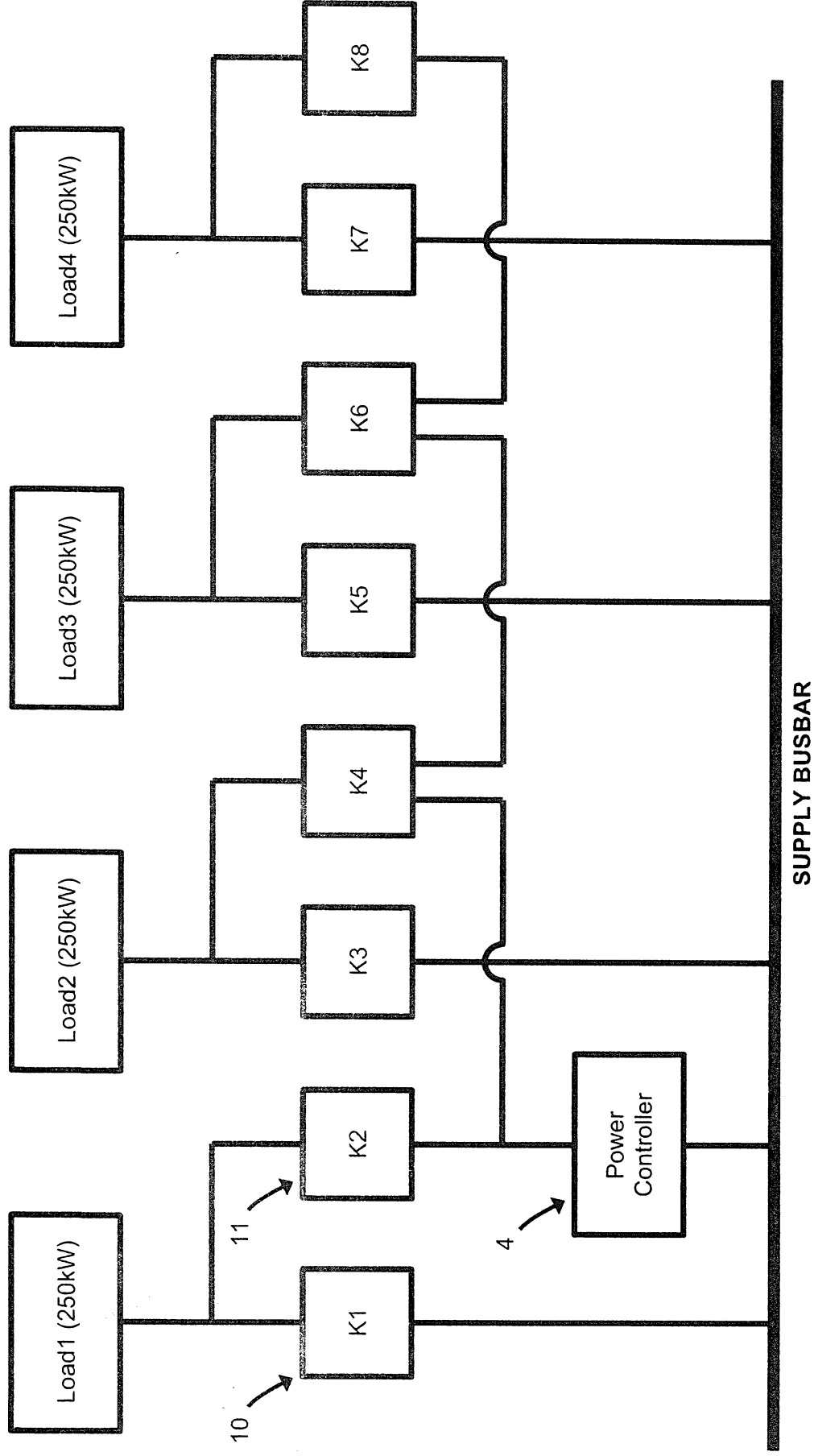


Fig. 5.0

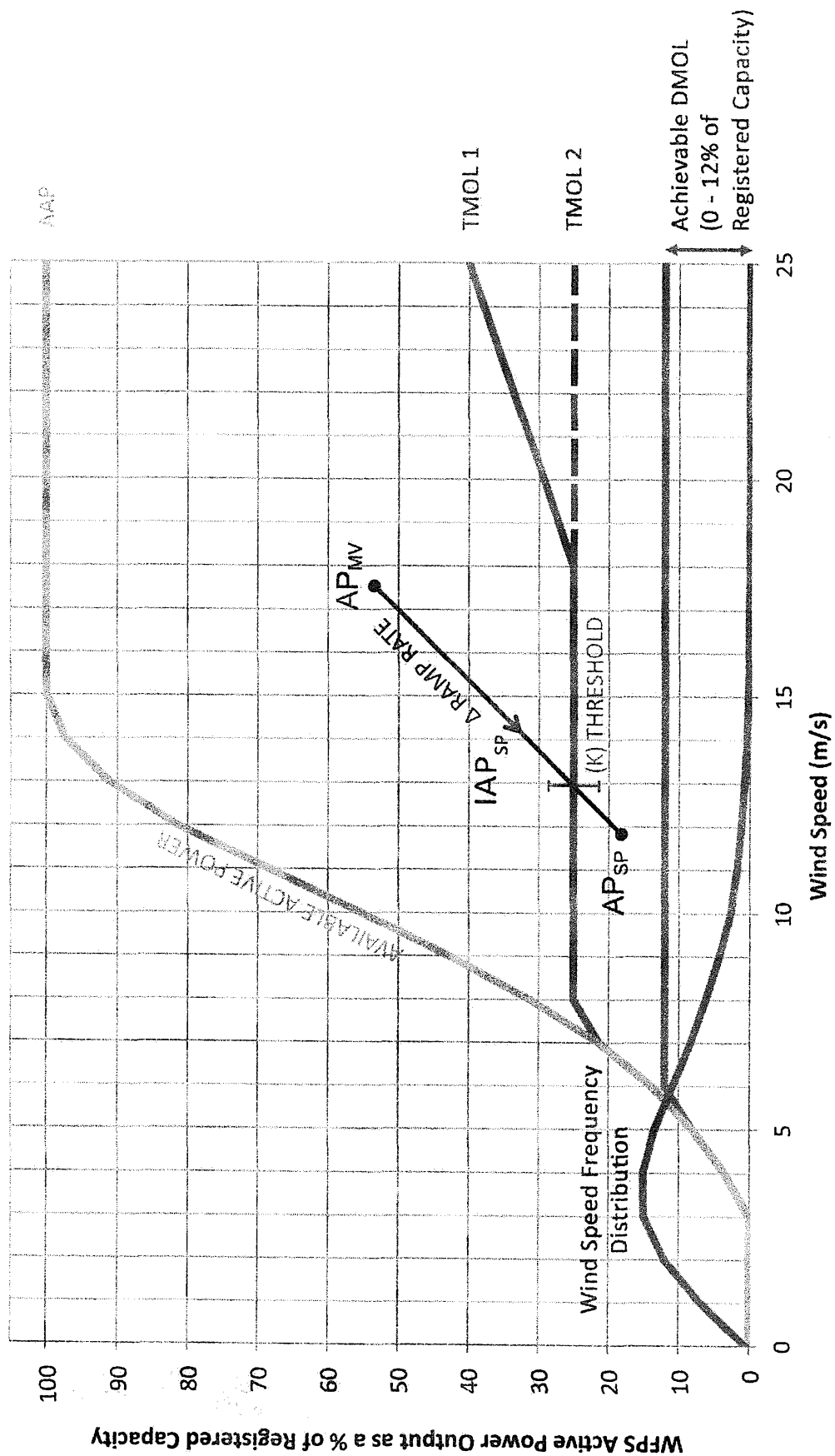


Fig. 6.0

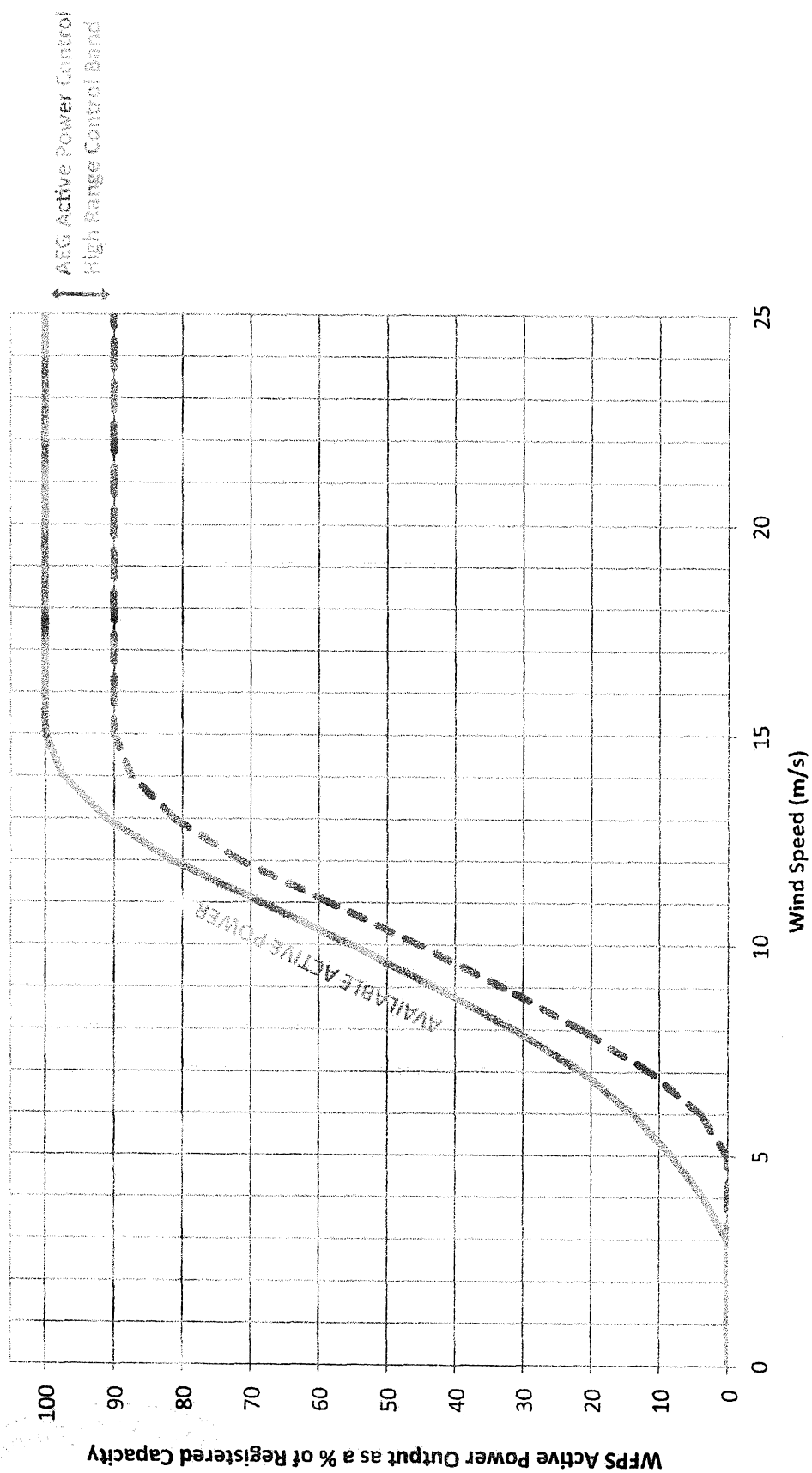


Fig. 7.0